JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

11100 Johns Hopkins Road
Laurel, MD 20723-6099

Initial Results from the Airborne Test Campaign of the Compact Midwave Imaging System (CMIS)

Presenter: Michael Kelly
PI: Michael Kelly
Team Members: J.L. Carr, I. Papusha, D. Wu, A. Goldberg, K. Yeakel, J. Boldt, C. A. Clayson, F. Ding

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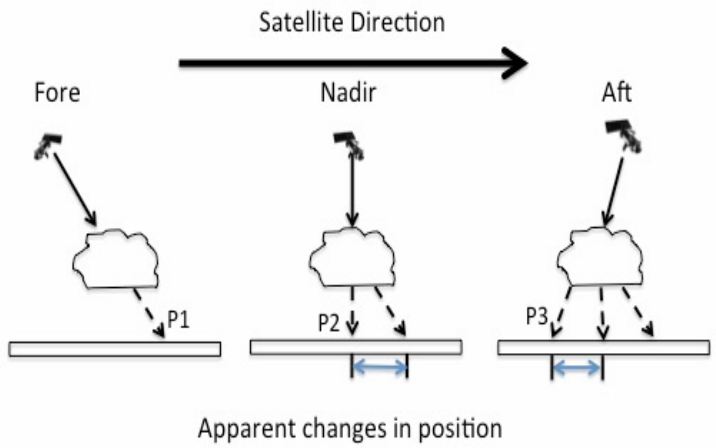
Challenging Problems

- Decadal Survey-Incubation identifies global PBL heights as a high priority
  - Multi-platform stereo photogrammetry based on a constellation of affordable compact imagers provide a promising technique for globally mapping PBL heights and 3D winds
  - Wind fields are derived from atmospheric motion vectors (AMVs) based on tracking clouds and aerosols
- Height assignment
  - Limitations with IR method
  - Limitations with single-platform stereo (e.g. MISR)
  - Stereo height from multi-angle, multi-platforms
- Small or hosted satellite solutions to provide affordable, yet better spatio-temporal coverage
  - LEO-GEO
  - GEO-GEO
  - Future: LEO-, GEO-CubeSat Constellation

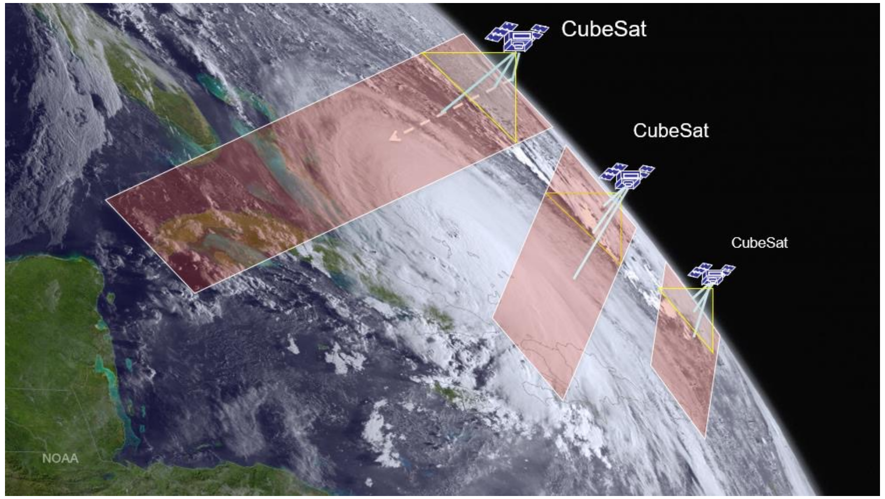
Passive-Sensing Stereo Methodology

- Fly midwave imagers to enable day/night stereo calculations using same techniques/bands
- Use imagers on **two** spacecraft several minutes apart to eliminate ambiguity in along-track direction between winds and cloud heights for atmospheric motion vectors (AMVs)
- Utilize cloud-top altitude for AMV height assignment to avoid large errors for thin clouds and temperature inversions



Advantages:

- Estimated CMV/CGH accuracy: ±0.5 m/s , ±200 m assuming 1/4-pixel **relative** geolocation accuracy (Carr et al 2018)
- Minimum detectable along-track precision: <1 m/s
- Wide-field of view coverage to complement future active instruments
- Flexible satellite accommodation – CubeSats or hosted on weather satellite



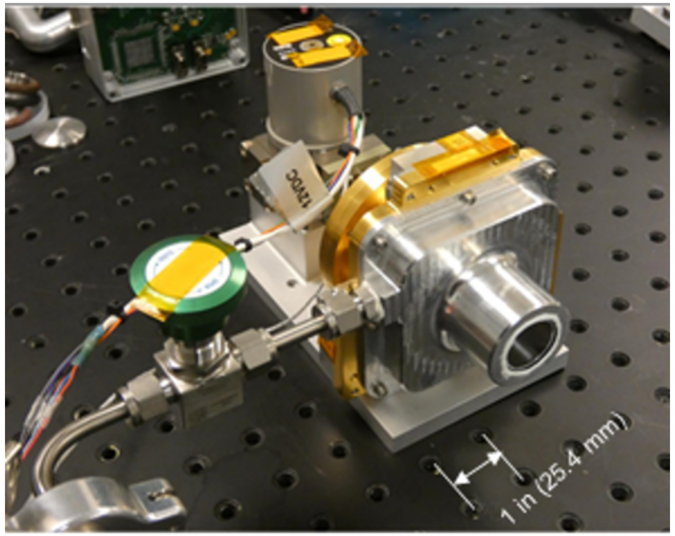
Compact Midwave Imaging System

- JHU/APL developed a compact shortwave/midwave imager with a 640x512 focal plane array (FPA) based on high operating temperature (HOT) technology:
  - Designed for day/night observations in the SWIR/MWIR
  - Enables global data collection of cold and warm temperatures between the poles and tropics due to wide dynamic range
  - Provides a novel capability to detect objects and weather with same FPA
- Employs multi-angle views (fore, nadir and aft) to retrieve heights and motions of objects
- Requires modest size, weight and power (SWaP) which permits accommodation on 6U CubeSats

Specifications

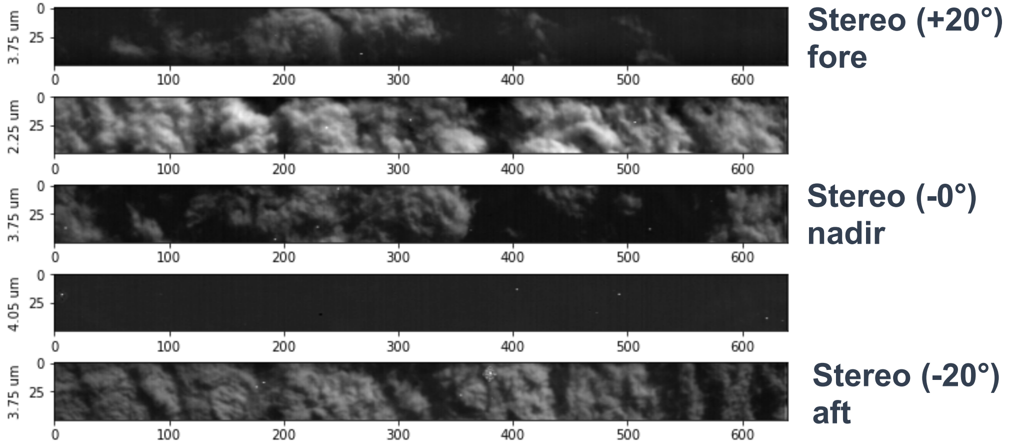
Field	Result
Multi-Spectral	2.25, 3.75, 4.05 µm
Multi-Angle	20°, 0°, -20° views at 3.75 µm
Weight, Power	< 3 kg, 7 W
Operating Temperature	150 K
NEdT	< 1 K for 230 K and 400 K
Readiness	Radiation, vibration tested

Airborne Model

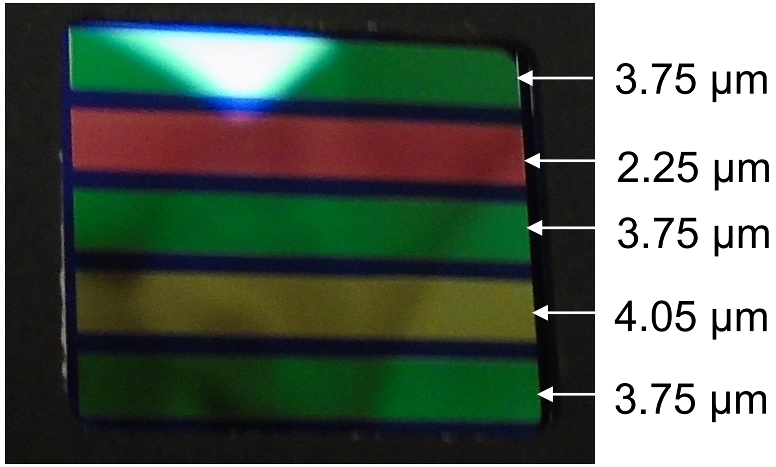


Successful Airborne Flight Demonstration

CMIS Snapshot



Filter design

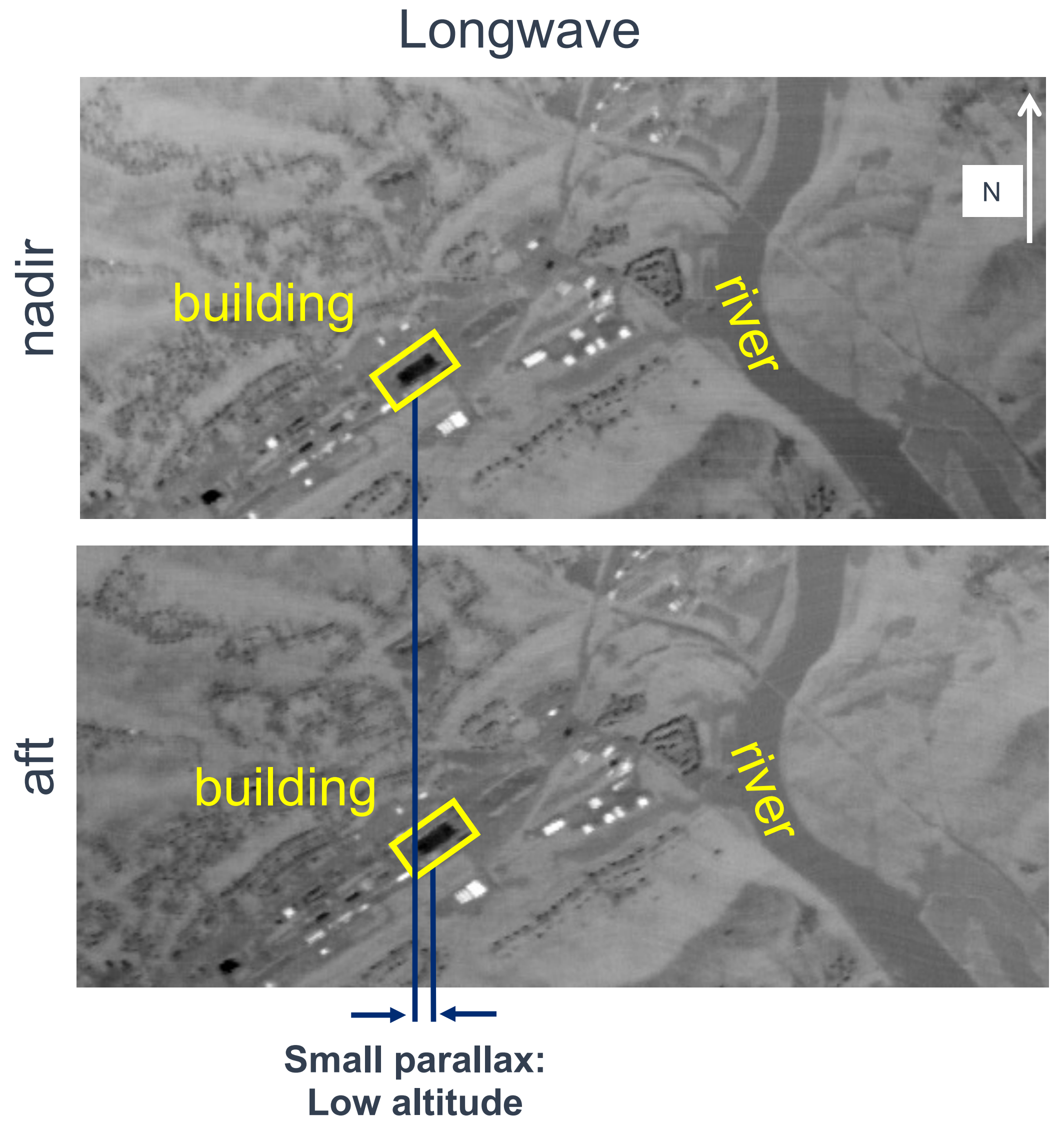


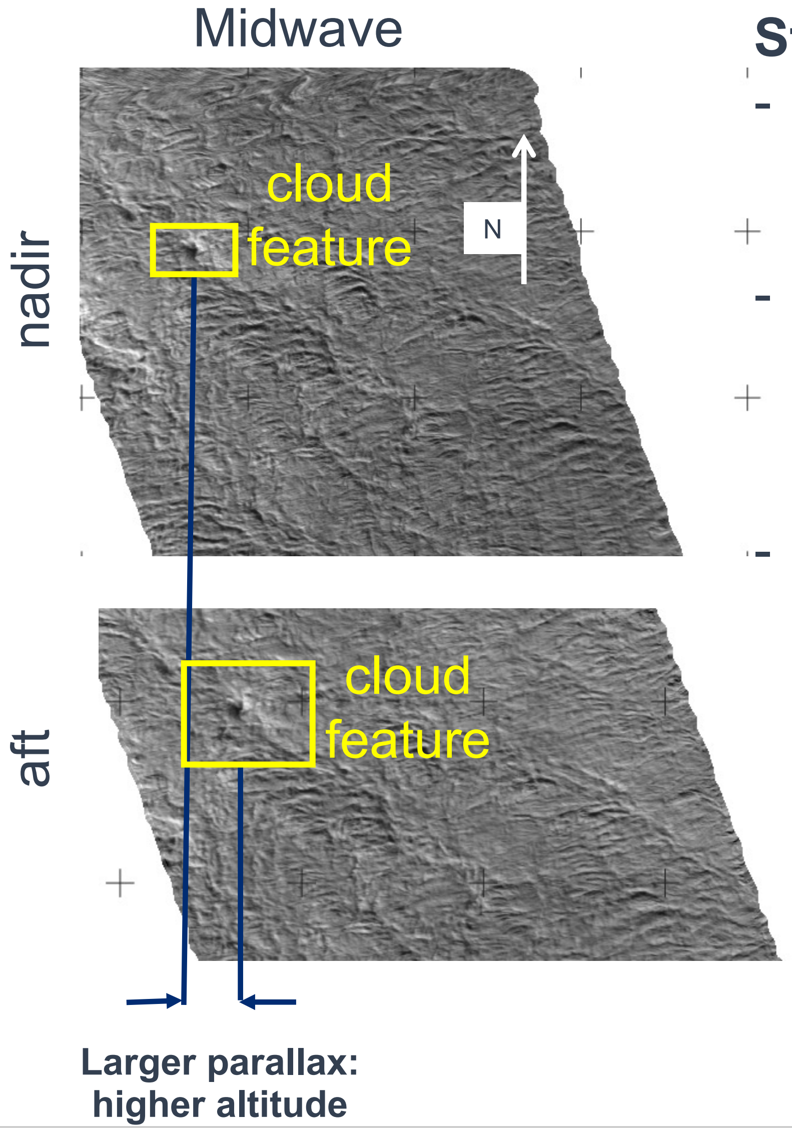
NASA GIII

Airborne Test Campaign
22 Jan-8 Feb 2021
NASA Langley

- Provides multi-angle, multi-spectral imagery based on striped filter
- **Proved** that low-cost compact imager can provide high-quality datasets
- Could include wavelength stripes to support atmospheric motion vectors, cloud heights, and **weather**, for example

Stereo Methodology

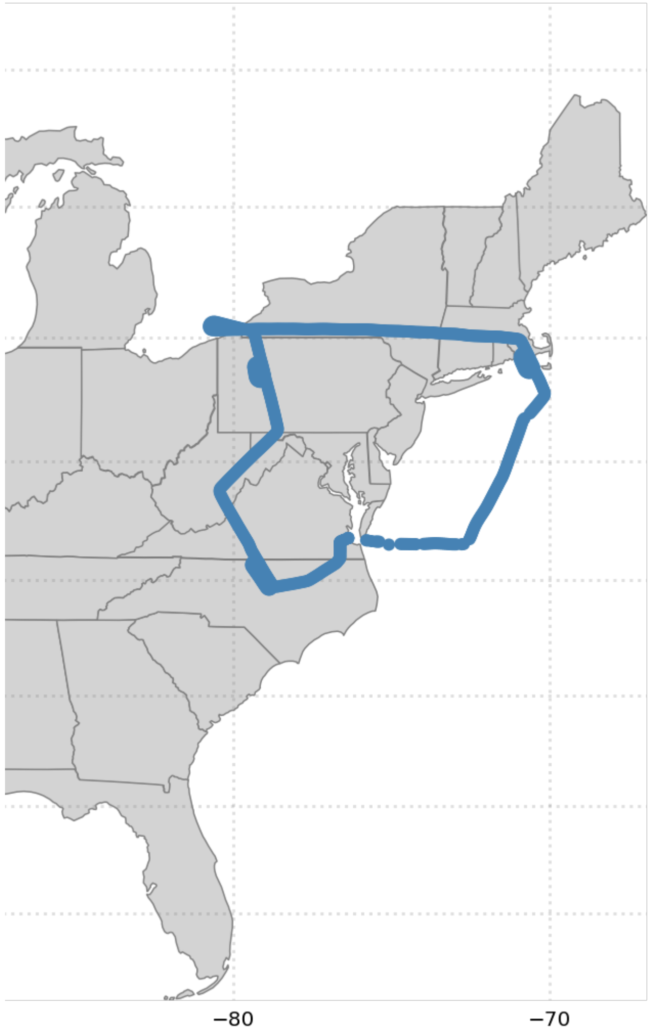


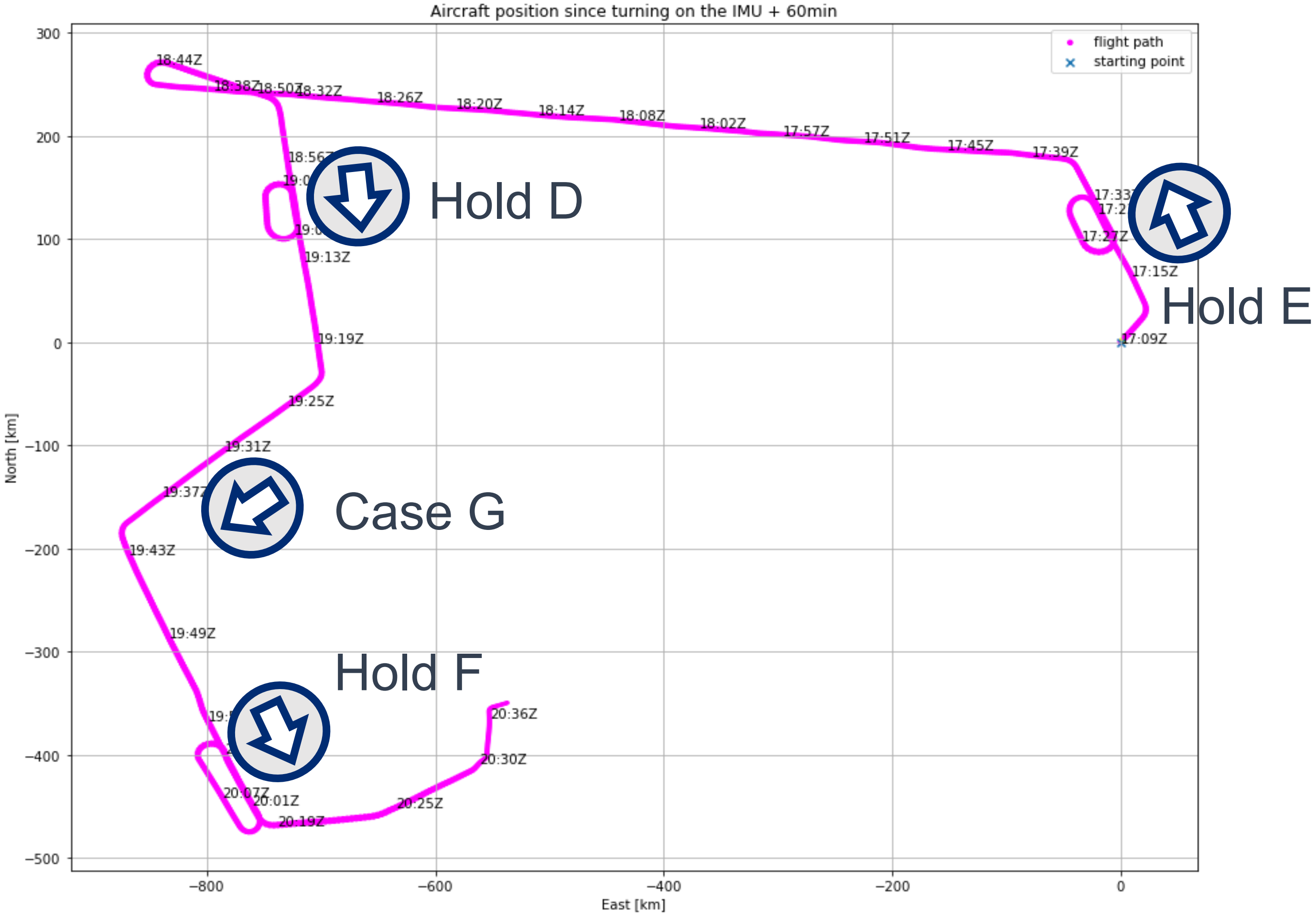


Stereo Methodology

- Applicable to weather and non-weather features
- Does not need multiple wavelengths for cloud heights
- Do not need multiple wavelengths to discriminate between snow/clouds

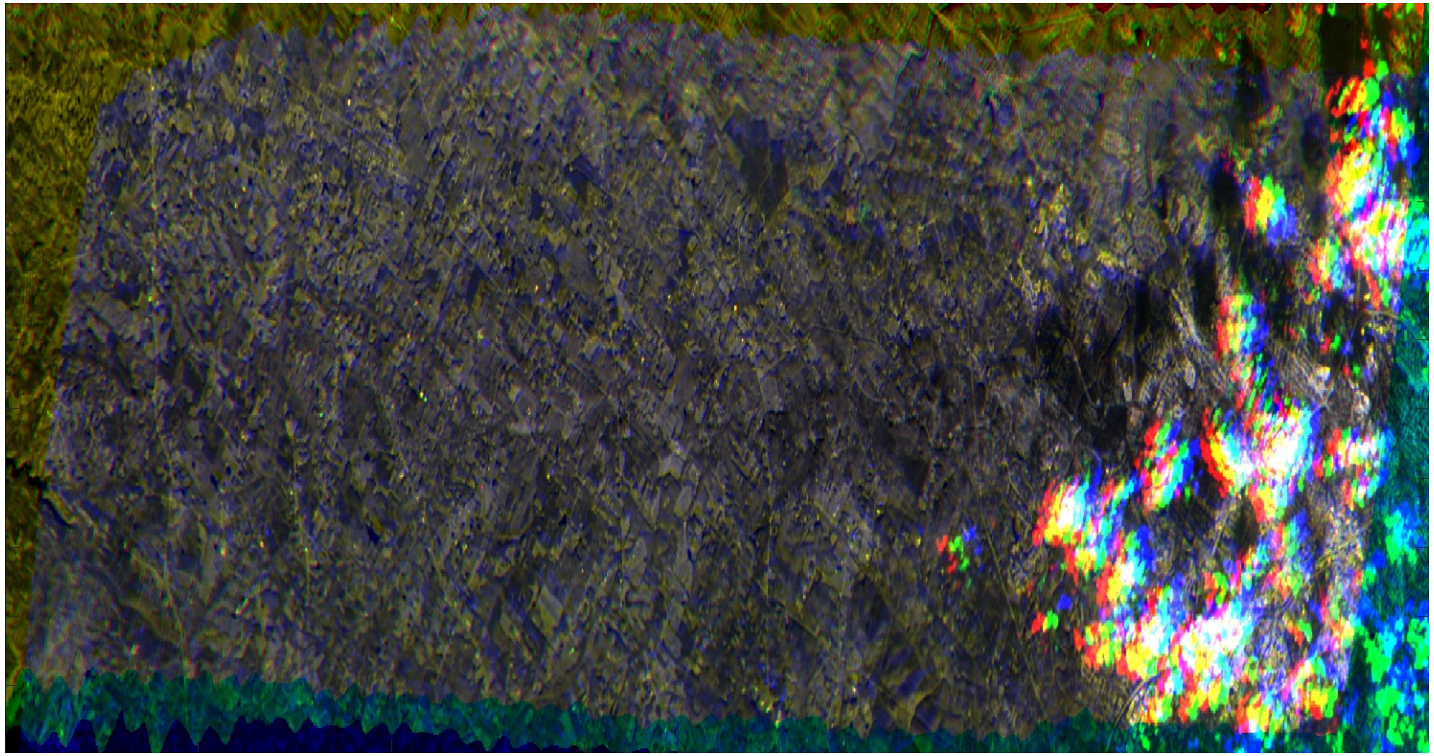
Science Flight #1 – 27 Jan 2021





Prepared Imagery for StereoBit* Pipeline

Hold F2



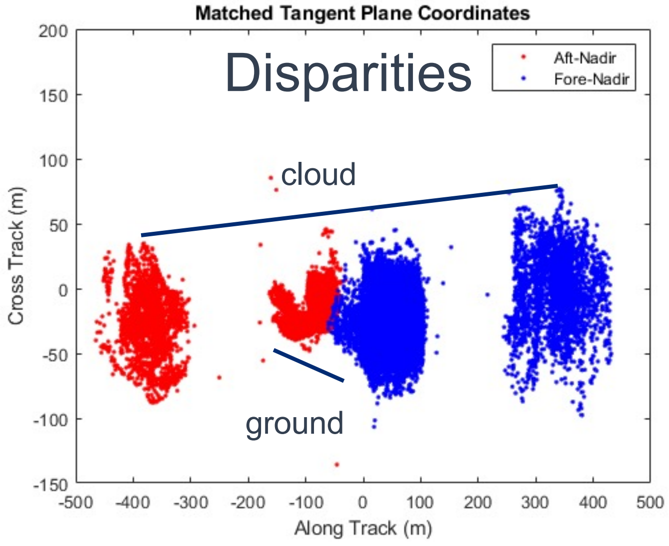
- Initial coarsely aligned triplet of CMIS fore, nadir, aft imagery
- Gray region indicates overlap between all three in the triplet
- Color separation indicates parallax and/or motion

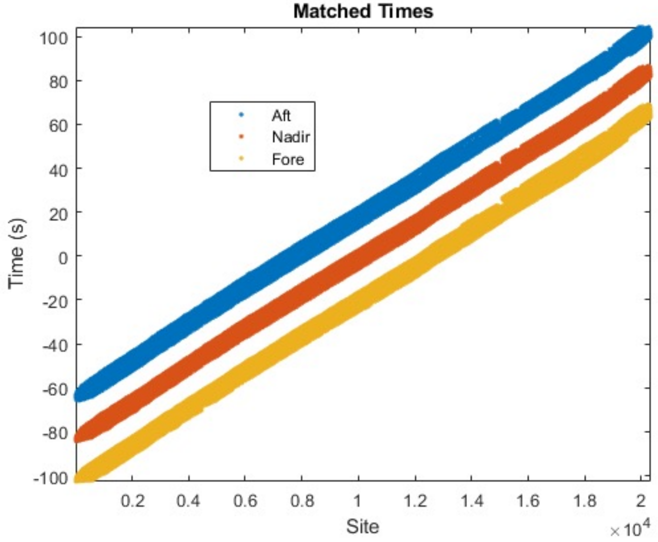
AIST-18-0082

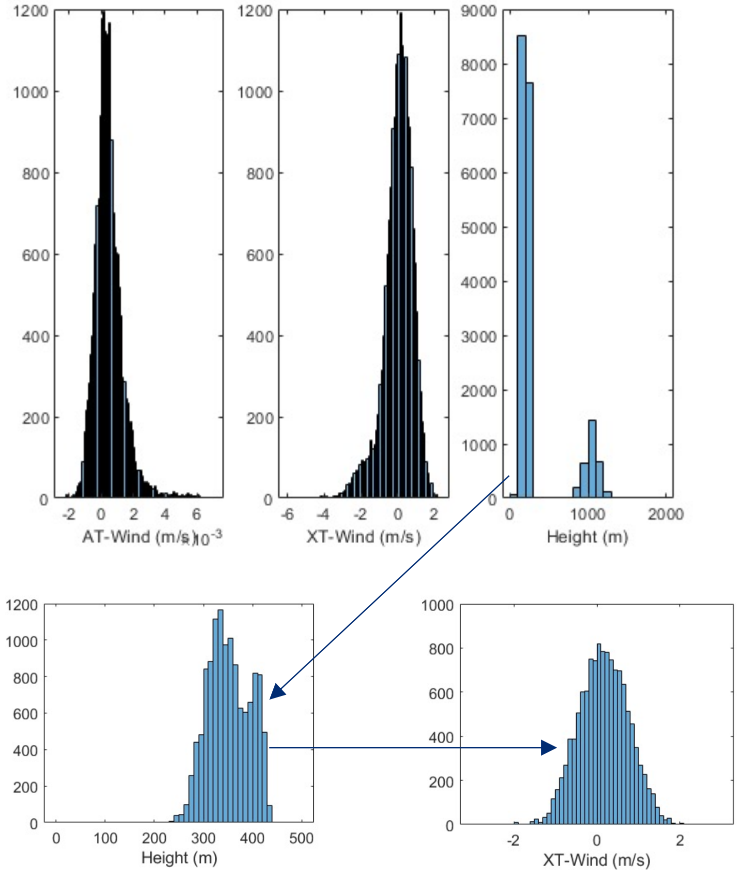
StereoBit: An ESTO AIST project to enable onboard processing of stereo images

Retrievals for Hold F2

- Disparities measure the apparent difference in location between fore-nadir and nadir-aft
- Notice two sets of disparities with one corresponding to ground and other to clouds at 1000 m



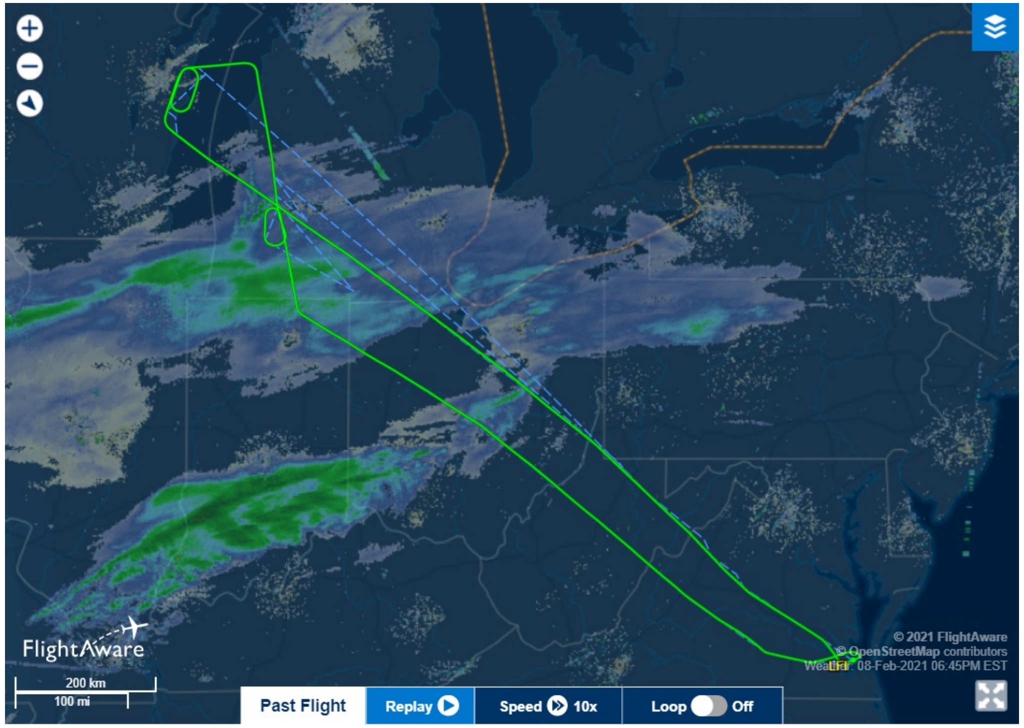




Median DEM Height ~275 m

Night Flight – 8 Feb 2021

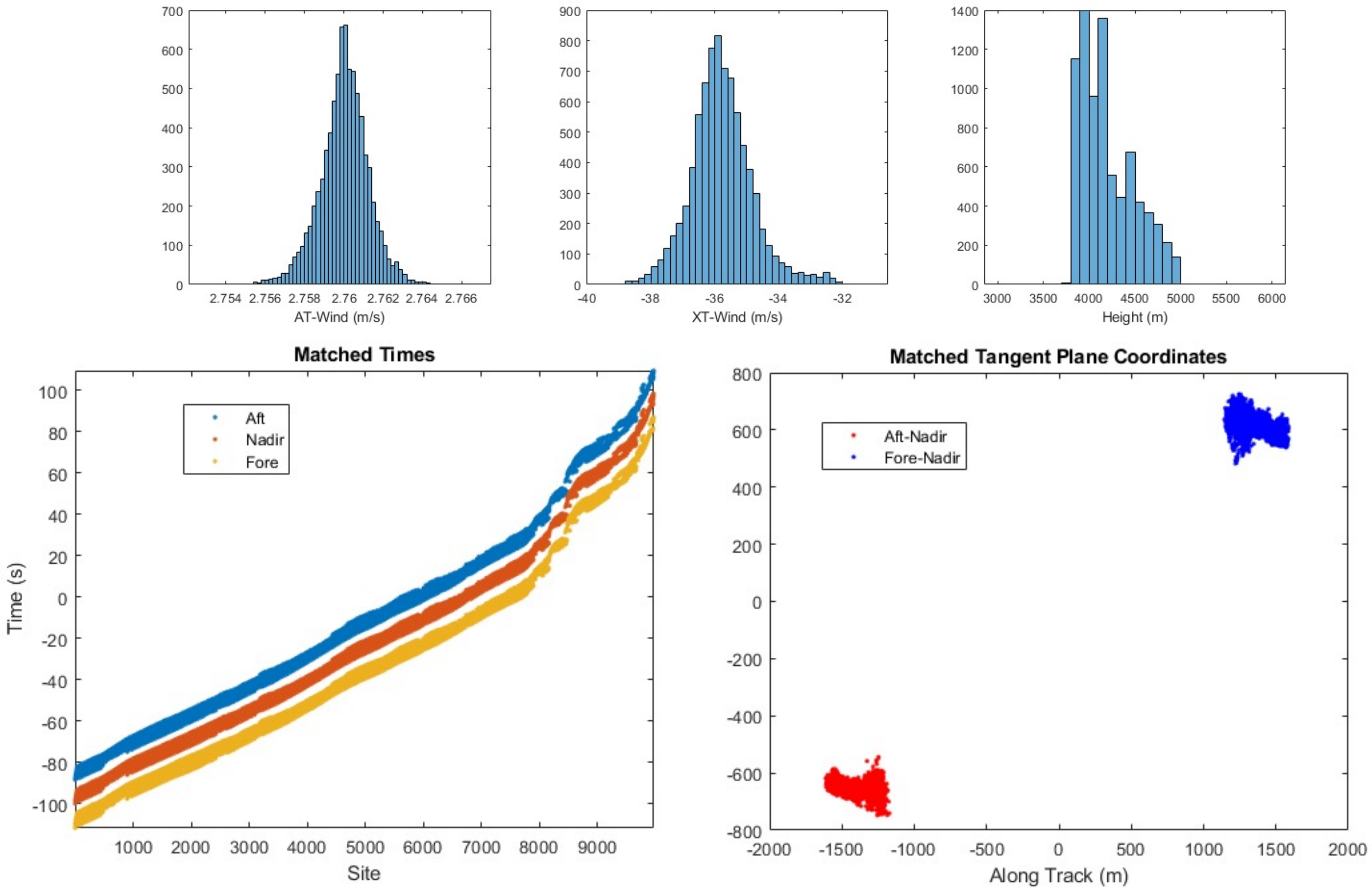
NASA LaRC Gulfstream-3



Flight Track, 8 Feb 2021

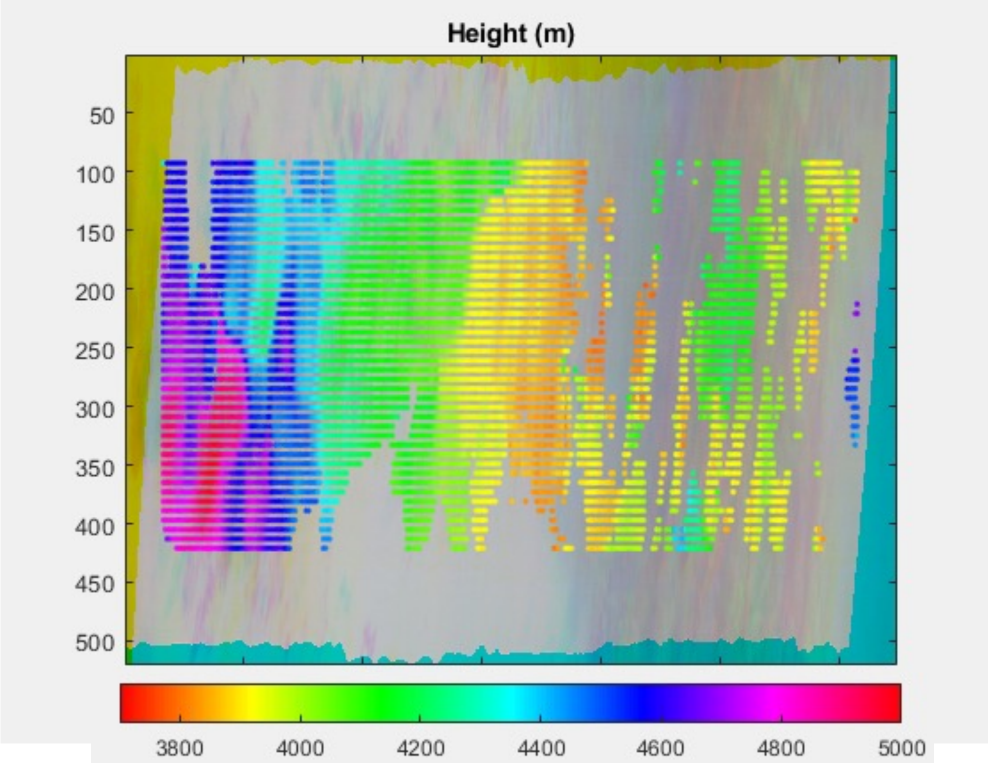
Purpose: Underfly Aeolus and GOES
Nighttime data collection
Collect on cold surface and Lake Michigan at night

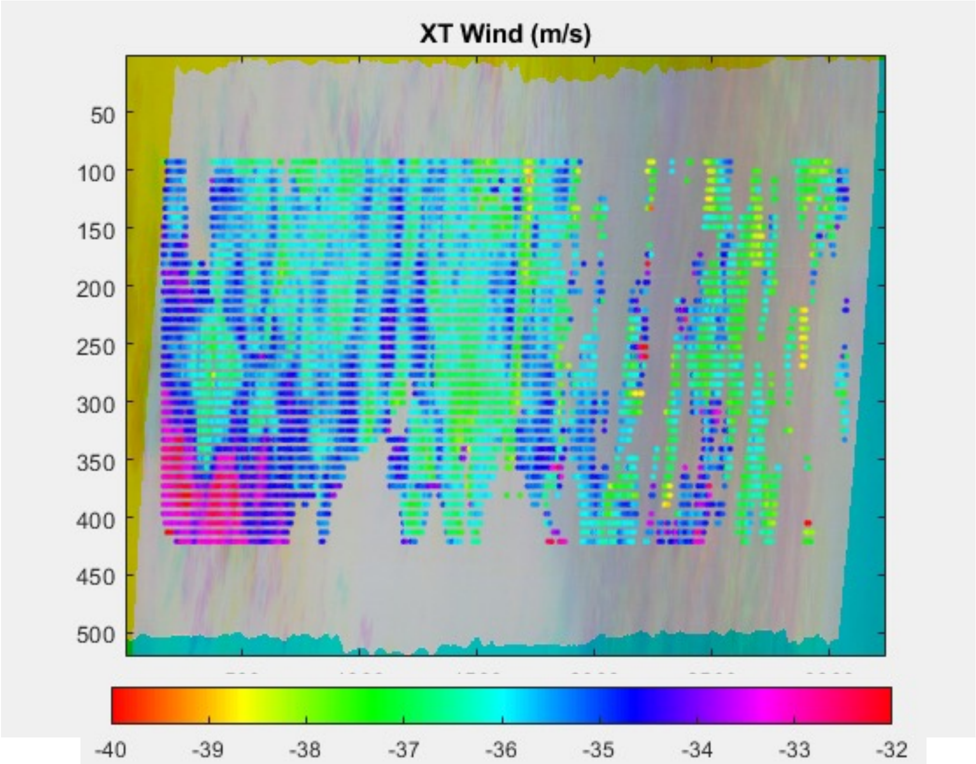
Hold J1 Retrievals



- Along-track winds specified from GOES-GOES retrieval
- Disparities well separated due to high winds
- Primary altitude for for clouds is ~4 km and winds 36 m/s

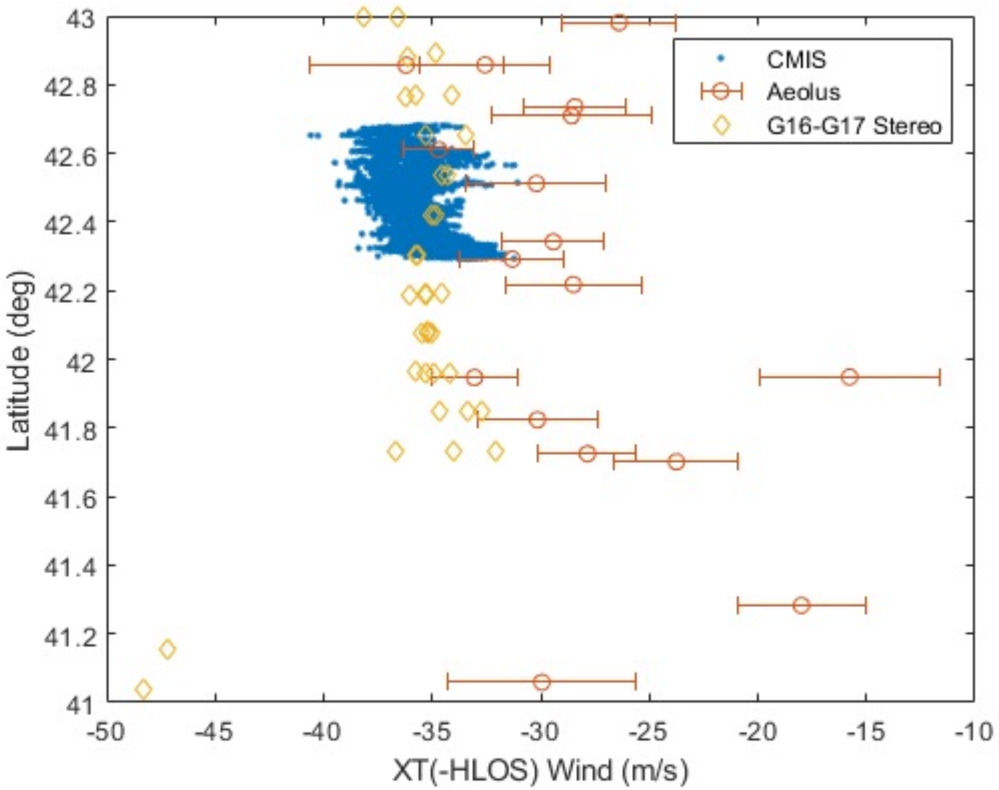
Heat maps for Hold J

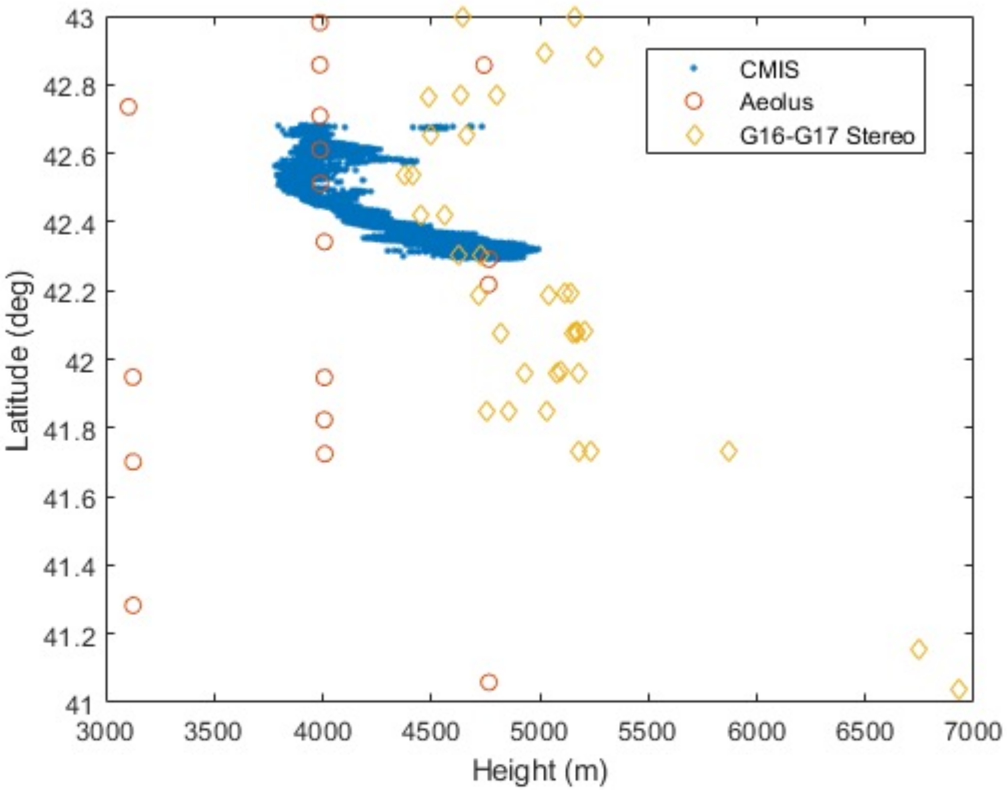




	mean	median	min	max	sigma
Height (m)	4201	4126	3781	4994	294
XT Wind (m/s)	-35.77	-35.83	-39.48	-31.06	0.99

Inter-Comparison with GOES and Aeolus





- CMIS heights, cross-track winds consistent with Aeolus and GOES
- Primary cloud-top altitude and winds for this case are ~4-5 km and 35.83 m/s
- CMIS demonstrated good sensitivity to small-scale variability

Summary and Conclusions

- Initial results/comparison with Aeolus and GOES very encouraging
- **Demonstrated** that low-cost compact imager can provide high-quality datasets for science
- Aircraft Problem ***more difficult*** than Spacecraft Problem
- Success of airborne campaign demonstrates CMIS readiness for spaceflight

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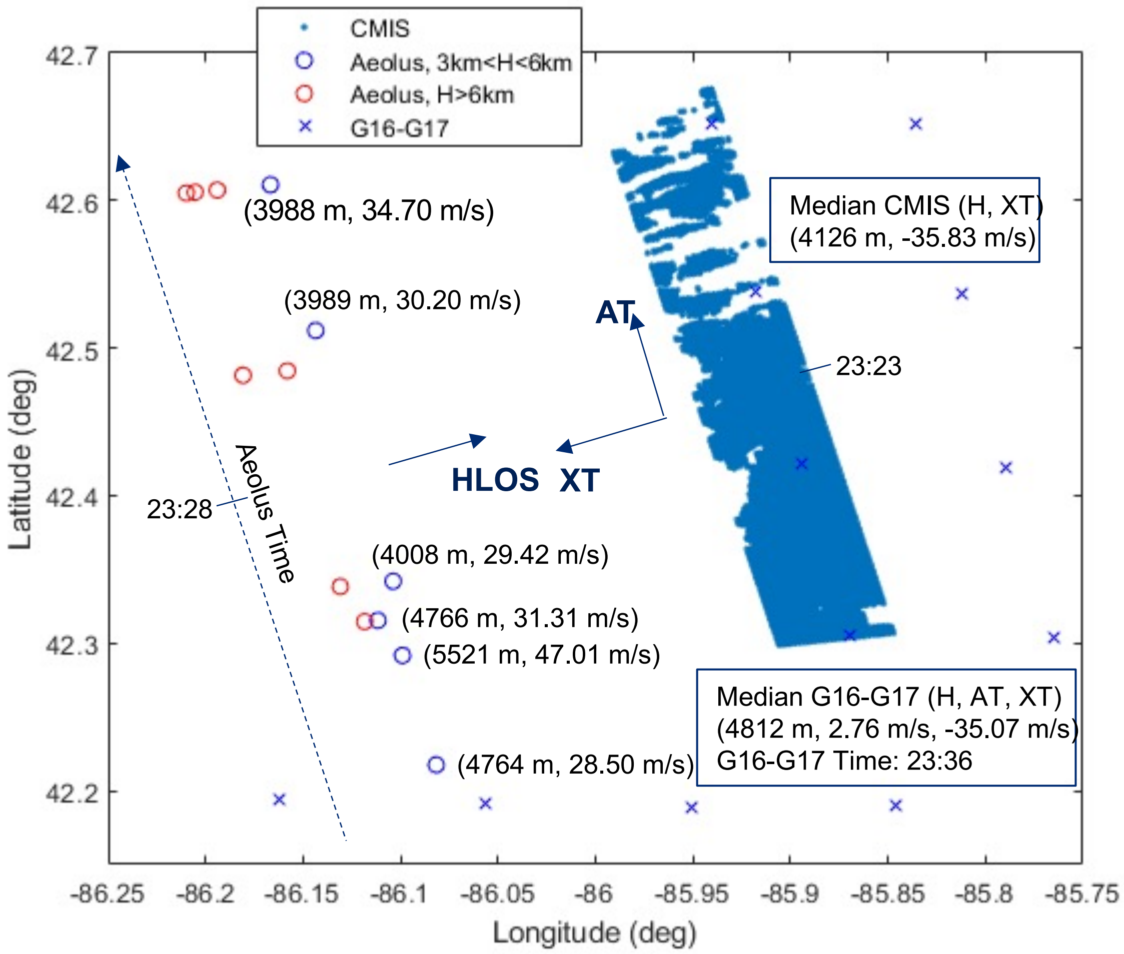
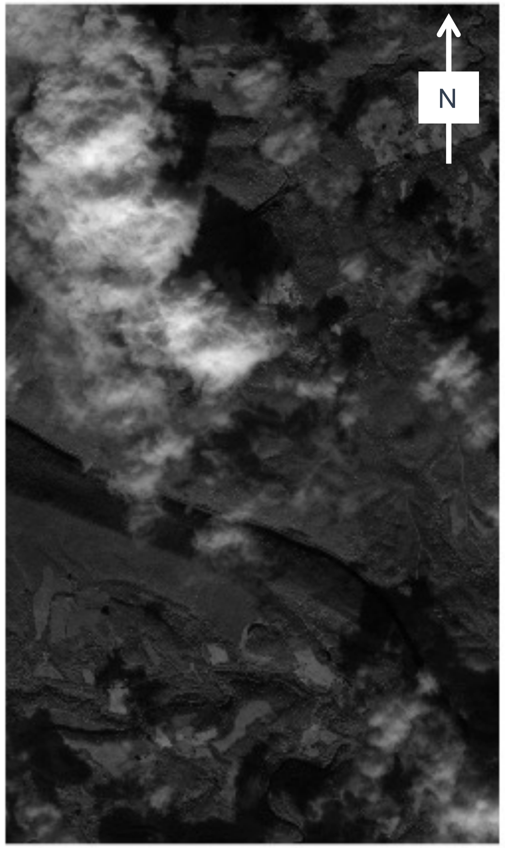
Comparison with Aeolus



- CMIS coverage slightly east of the Aeolus coverage
- CMIS heights, cross-track winds consistent with Aeolus
- Primary altitude for for clouds is ~4.126 km and winds 35.83 m/s

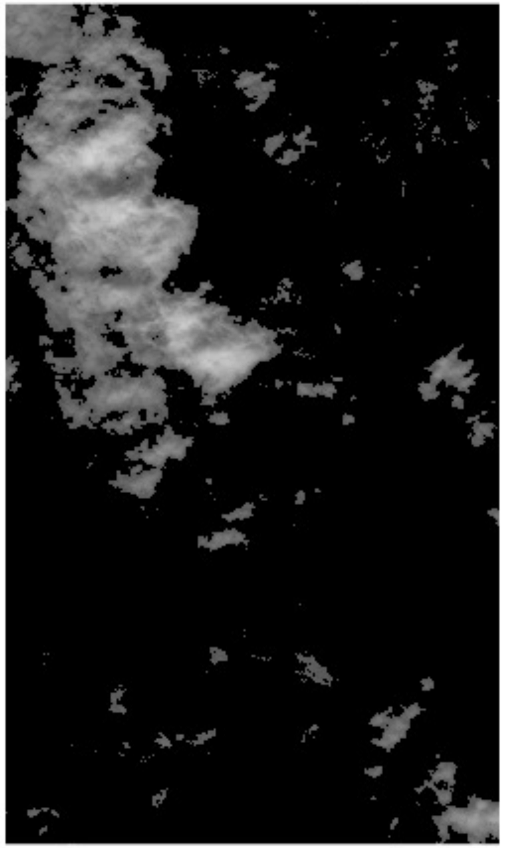
Motion Vectors

Fore: Overlap region (visible)



Fore: Radiance thresholded cloud mask

Fore: Clouds only



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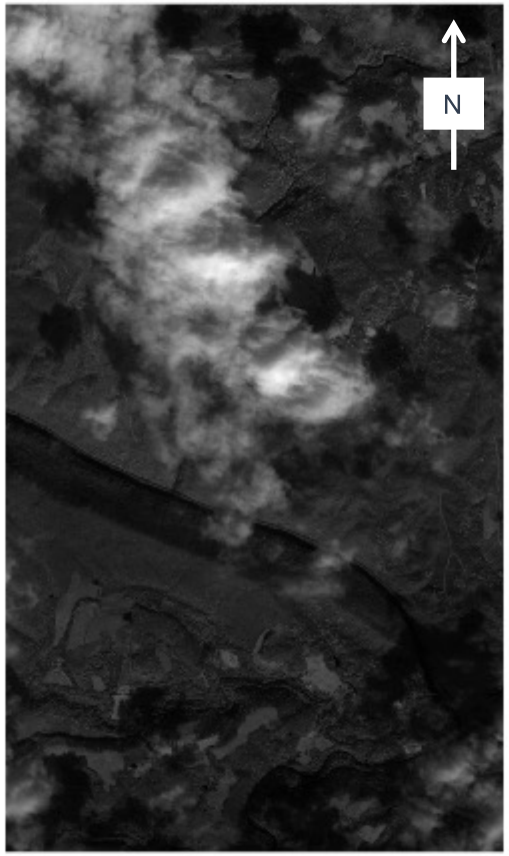
Motion Vectors

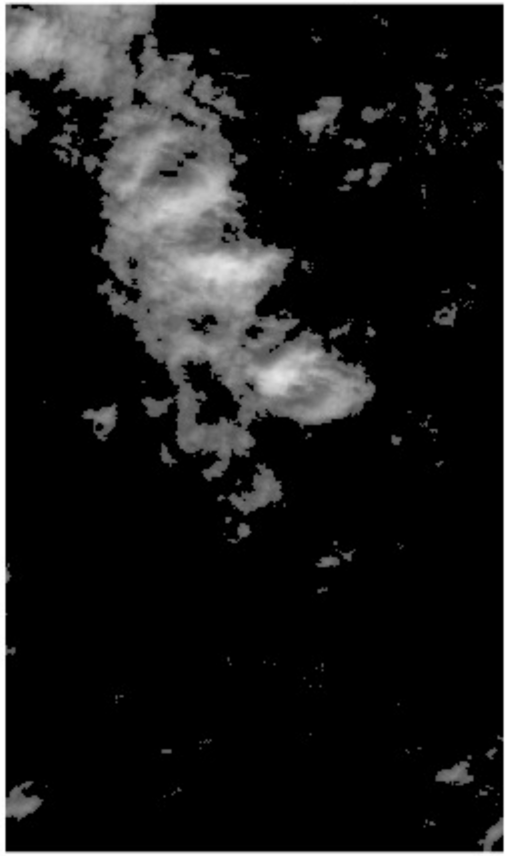
Observed: predominantly **eastward** cloud motion across fore-aft overlap region

Aft: Overlap region (visible)



Aft: Radiance thresholded cloud mask

Aft: Clouds only



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